Geophysical Investigations of a Suspected Historic Grave at Yellowstone National Park, Park County, Montana

Steven L. De Vore
Midwest Archaeological Center
National Park Service
Federal Building, Room 474
100 Centennial Mall North
Lincoln, Nebraska 68508-3873
February 2006

Submitted to Superintendent, Yellowstone National Park, Wyoming.

Introduction

The geophysical survey of a suspected historic 19th century grave at Yellowstone National Park (YELL) near Gardiner, Montana, was conducted between May 31 and June 1, 2005, by Midwest Archeological Center (MWAC) archeologist Steven De Vore. Located in Section 23, Township 9 South, Range 8 East, of Park County, Montana (Figure 1), the geophysical investigations were conducted at the request of the Yellowstone National Park cultural resource staff. The suspected unmarked grave was located within the northern boundary of the park on the outskirts of Gardiner, Montana. Located next to the park's maintenance outdoor storage area, the area of investigation was 100 square meters (10 m x 10 m). The geophysical investigations of the project area include a magnetic gradient survey with a fluxgate gradiometer, a conductivity and a magnetic susceptibility survey with a ground conductivity meter, a resistance survey with a resistance meter and twin probe array, and a ground penetrating radar survey with a ground penetrating radar cart system and 400 mHz antenna. The author was assisted during the geophysical survey by YELL archeologist Elaine Skinner Hale.

Based on information supplied by a local Gardiner resident, Jim Hepburn, the cultural resource staff was shown the grave location near the new Heritage and Research Center by Mr. Hepburn in 2003 (Elaine Skinner Hale, personal communications 2005). The grave location had been passed down to Mr. Hepburn from his grandfather over 70 years ago. In 2004, archeological investigations were conducted at the grave location by Dr. Danny Walker of the Office of the Wyoming State Archaeologist (Walker and Hale 2004). Using limited auger test holes along the edge of the stone cobbles demarcating the grave boundary, Dr. Walker found the soils and sediments to be mixed unlike the uniform soils outside of the suspected grave vicinity. Additional geophysical investigations were recommended by Dr. Walker.

Survey area: The project area is located in the Northern Rocky Mountains province of the Rocky Mountain System division of the North American continent (Fenneman 1931:183-224). The region consists of deeply dissected mountain uplands with intermont basins. The Gallatin Range lies to the west of the project area. The project area is located on left side of the Yellowstone River. The area also lies within the Montanian biotic province (Dice 1943:34-37). The climate is continental with severe, cold winters and cool summers (Rodman et al. 1996:5). The project area is located within the Gateson Family-Pesowyo Family-Eaglewing Family complex (1721F). This soil complex formed on alluvial fans under nonforest vegetation in a frigid temperature regime (Rodman et al.1996:29-31). Sedimentary rocks form the main components of the fan alluvium in the surficial deposits. The main soils are nonskeletal Inceptisols, nonskeletal Alfisols, and skeletal Mollisols (Rodman et al. 1996:29). The pH levels in these soils range from strongly acid to moderately alkaline (Rodman et al. 1996:174,178,205). Ground vegetation includes sagebrush, prickly pear cactus, and bunch grasses. Ground visibility is very high with more than 90% visibility. A small intermittent drainage flowing into the Yellowstone River is located west of the geophysical project area.

Surface features: The project area was surrounded by a snow fence and steel posts (Figure 2). A series of small cobbles provide an "L" shaped outline on the west and south side of the suspected grave (Figure 3). The use of stone to outline the grave was noted by the author during a visit to the neighboring Gardner Cemetery and isolated grave on the Stoll Ranch property near the present project area (Whittlesey 2003). In addition to the cobbles, pin flags from Dr. Walker's 2004 investigations were in place marking the location of the auger tests.

Subsurface features: The extent of buried features in the project area is presently unknown with the exception of the possible grave. To the west of the geophysical project area, there is located a historic and prehistoric component site.

Survey Methodology

The geophysical survey was conducted at the request of Yellowstone National Park staff. In order to identify any buried archeological resources in the proposed project area, the Midwest Archeological Center (MWAC) and YELL archeologists applied magnetic gradient, conductivity, magnetic susceptibility, resistance, and ground penetrating radar survey techniques to investigate and identify the extent and location of possible archeological features associated with the suspected grave. The snow fence and steel fence posts were removed from the survey area before laying out the geophysical grid. A 10 meter north-south by 10 meter east-west geophysical survey area was established around the suspected grave location. Wooden stakes were placed at the 10-meter grid unit corners with a surveying compass (Ushikata 2005). The geophysical grid oriented on magnetic north. The four corners of the geophysical grid were also surveyed with a Trimble GeoExplorer 3 global positioning system unit (Trimble 1999). Prior to setting up the geophysical survey ropes, surface materials including a 2-inch pipe and sections of sheet metal were removed from the survey grid.

Geophysical survey ropes were placed along the east-west base lines connecting the grid unit corners. These ropes formed the north and south boundaries of the survey grid unit during the data collection phase of the survey (Figure 4). Additional ropes were placed at one-meter intervals across the grid unit in a north-south orientation. These ropes served as guides during the data acquisition phase. The ropes were marked with different color tape at half-meter and meter increments designed to help guide the survey effort. A sketch map was completed for the survey location (Figure 5). The data were acquired across the grid units beginning in the lower left hand corner of the grid unit.

Survey grids: One complete 10 meter by 10 meter grid units (100 m^2 or 0.025 acres) was surveyed (Figure 6).

Geophysical Survey Techniques

Geophysical prospection techniques available for archeological investigations consist of a number of techniques that record the various physical properties of the earth, typically in the upper couple of meters; however, deeper prospection can be utilized if necessary (David 1995). Geophysical techniques are divided between passive techniques and active techniques. Passive techniques are primarily ones that measure inherently or naturally occurring local or planetary fields created by earth related processes (Heimmer and De Vore 1995:7,2000:55; Kvamme 2001:356). The primary passive method utilized in archeology is magnetic surveying. Other passive methods with limited archeological applications include self-potential methods, gravity survey techniques, and differential thermal analysis. Active techniques transmit an electrical, electromagnetic, or acoustic signal into the ground (Heimmer and De Vore 1995:9,2000:58-59; Kvamme 2001:355-356). The interaction of these signals with buried materials produces alternated return signals that are measured by the appropriate geophysical instruments. Changes in the transmitted signal of amplitude, frequency, wavelength, and time delay properties may also be observable. Active methods applicable to archeological investigations include electrical resistivity, electromagnetic conductivity (including ground conductivity and metal detectors), magnetic susceptibility, and ground penetrating radar. Active acoustic techniques, including seismic, sonar, and acoustic sounding, have very limited or specific archeological applications.

Magnetic Gradient Survey

Instrument: Geoscan Research FM36 fluxgate gradiometer (Geoscan Research 1987)

Specifications: 0.05 nT (nanotesla) resolution, 0.1 nT absolute accuracy

Survey type: magnetic gradient

Operators: Steven De Vore

A magnetic gradient survey is a passive geophysical survey (see Bevan 1998:18-29; Clark 2000:64-98; David 1995:17-20; Gaffney and Gater 2003:36-42,61-72; Gaffney et al. 1991:3-5,2002:7-9; Heimmer and De Vore 1995:7-20,2000:55-58; Kvamme 2001:357-358,2003:441,2005:434-436; Lowrie 1997:229-306; Milsom 2003:51-70; Mussett and Khan 2000:139-180; Scollar et al. 1990:375-519; Sharma 1997:65-111, and Weymouth 1986:341-370 for more details of magnetic surveys). The Geoscan Research FM36 fluxgate gradiometer (Figure 7) is a vector magnetometer, which measures the strength of the magnetic field in a particular direction. The sensors must be accurately balanced and aligned along the direction of the field component to be measured. Reference points for balancing and aligning the gradiometer and for zeroing the conductivity meter was selected at the southwest corner of the geophysical grid. The two magnetic sensors in the instrument are spaced 0.5 meters apart. The instrument is carried so the two sensors are vertical to one another with the bottom sensor approximately 30 cm above the ground. Each sensor reads the magnetic field strength at its height above the ground. The gradient or change of the magnetic field strength between the two sensors is recorded in the instrument's memory. This gradient is not in absolute field values but rather voltage changes, which are calibrated in terms of the magnetic field. The fluxgate gradiometer does provide a continuous record of the magnetic field strength.

A magnetic survey is a passive geophysical prospection technique used to measure the earth's total magnetic field at a point location. Its application to archeology results from the local effects of magnetic materials on the earth's magnetic field. These anomalous conditions result from magnetic materials and minerals buried in the soil matrix. Iron artifacts have very strong effects on the local earth's magnetic field. Other cultural features, which affect the local earth's magnetic field, include fire hearths, and soil disturbances (e.g., pits, mounds, wells, pithouses, and dugouts), as well as, geological strata. Magnetic field strength is measured in nanoteslas (nT; Sheriff 1973:148). In North America, the earth's magnetic field strength ranges from 40,000 to 60,000 nT with an inclination of approximately 60° to 75° (Milsom 1996:43; Weymouth 1986:341). The project area has a magnetic field strength of approximately 55,700 nT with an inclination of approximately 70° 21' (Sharma 1997:72-73). Magnetic anomalies of archeological interest are often in the ±5 nT range, especially on prehistoric sites. Target depth in magnetic surveys depends on the magnetic susceptibility of the soil and the buried features and objects. For most archeological surveys, target depth is generally confined to the upper one to two meters below the ground surface with three meters representing the maximum limit (Clark 2000:78-80; Kvamme 2001:358). Magnetic surveying applications to archeological investigations have included the detection of architectural features, soil disturbances, and magnetic objects (Bevan 1991; Clark 2000;92-98; Gaffney et al. 1991:6; Heimmer and DeVore 1995; Heimmer and DeVore 2000; Weymouth 1986:343).

The magnetic gradient survey was designed to collect 8 samples per meter along 0.5 meter traverses or 16 data values per square meter. The data were collected in a parallel or unidirectional fashion with the surveyor maintaining the same direction of travel for each traverse across the grid. A total of 1,600 data values were collected during the survey of the 10 by 10 meter grid unit. The magnetic data were recorded in the memory of the gradiometer and downloaded to a laptop computer at the completion of the survey. The magnetic data were imported into Geoscan Research's GEOPLOT software

(Geoscan Research 2001) for processing. Both shade relief and trace line plots were generated in the field before the instrument's memory was cleared. Upon completion of the survey, the data were processed in GEOPLOT. The grid data file was transformed into a composite file and a zero mean traverse was applied to remove any traverse discontinuities that may have occurred from operator handling or heading errors. Upon completion of the zero mean traverse function, the data were interpolated by expanding the number of data points in the traverse direction and by reducing the number of data points in the sampling direction to provide a smoother appearance in the data set and to enhance the operation of the low pass filter. This changed the original 8 x 2 data point matrix into a 4 x 4 data point matrix. The low pass filter was then applied over the entire data set to remove any high frequency, small scale spatial detail. This transformation may result in the improved visibility of larger, weak archeological features. The data were then exported as an ASCII dat file and placed in the SURFER 8 contouring and 3d surface mapping program (Golden Software 2002). An image map of the magnetic gradient data was generated for the YELL survey grid area (Figure 8). The magnetic data from the geophysical survey area ranged from -172.8 nT to 169.9 nT with a mean of -3.008 nT and a standard deviation of 22.582 nT.

Resistivity Survey

Instrument: Geoscan Research RM15 resistance meter with PA5 multiprobe array (Geoscan Research 1996)

Specifications: 0.05 ohms resolution, 0.1 ohms absolute accuracy

Survey type: resistance

Operators: Steven De Vore and Elaine Hale

The resistance survey is an active geophysical technique, which injects a current into the ground (see Bevan 1998:7-18; Carr 1982; Clark 2000:27-63,171-175; David 1995: 27-28; Gaffney and Gater 2003:26-36; Gaffney et al. 1991:3-5,2002:7-9; Heimmer and De Vore 1995:29-35,2000:59-60; Kvamme 2001:358-362,2003:441-442,2005:434-436; Lowrie 1997:203-219; Milsom 2003:83-116; Mussett and Khan 2000:181-232; Scollar et al. 1990:307-374; Sharma 1997:207-264, and Weymouth 1986:318-341 for more details of resistivity surveys). The voltage is measured and by Ohm's Law, one may compute the resistance at any given point (**R=V/I** where **R** is resistance, **V** is voltage, and **I** is current). Resistance or opposition to the current flow is measures in ohms (Sheriff 1973:156,184). Due to the problem of contact resistance between two electrodes in the ground, a typical resistance survey makes use of four electrodes or probes. The current passes through two electrodes and the voltage is measured between the other two probes. The configuration of the electrodes also varies (see Milsom1996:73 and Weymouth 1986:324 for common configurations).

Resistance or resistivity changes result from electrical properties of the soil matrix. Changes are caused by materials buried in the soil, differences in soil formation processes, or disturbances from natural or cultural modifications to the soil. In archeology, the instrument is used to identify areas of compaction and excavation, as well as, buried objects such as brick or stone foundations. It has the potential to identify cultural features that are affected by the water saturation in the soil, which is directly related to soil porosity, permeability, and chemical mature of entrapped moisture (Clark 2000; Heimmer and De Vore 1995:30). Its application to archeology results from the ability of the instrument to detect lateral changes on a rapid data acquisition, high resolution basis, where observable contrasts exist. Lateral changes in anthropogenic features result from compaction, structural material changes, buried objects, excavation, habitation sites, and other features affecting water saturation (Heimmer and De Vore 1995:37). The resistivity survey may sometimes detect the disturbed soil matrix within the grave shaft.

The Geoscan Research RM15 resistance meter uses the PA5 multiple probe array (Geoscan Research 1996). Arranged as a twin probe array, a current and voltage probes are located on a mobile frame, which is moved around the site (Figure 9). Two additional probes are located away from the survey area, which also consist of a current probe and voltage probe. The remote probes are set a distance 30 times the mobile probe separation. The probes on the frame are located at a fixed distance apart. A general rule of thumb for the depth investigation of resistance survey is the depth is equal to the distance of probe separation. This value is not a unique number but an average for the volume of soil 0.5 meters depth and a surface radius of 0.5 meters under the center point of the instrument frame. The probes are connected to the resistance meter, which is also on the frame. Wings may be added to the frame to expand the separation distance of the probes; however, this requires the resurvey of the grid for each change in the probe separation distance. The measurement is taken when the mobile probes make contact with the ground and complete the electrical circuit. The readings are stored in the resistance meter's memory until downloaded to a lap-top computer.

The resistance survey was designed to collect 2 samples per meter along 0.5 meter traverses or 4 data values per square meter. The data were collected in a zigzag fashion with the surveyor alternating the direction of travel for each traverse across the grid. A total of 400 data values were collected during the survey of the grid unit. The resistance data were recorded in the memory of the resistance meter and downloaded to a laptop computer at the completion of the survey. The resistance data were imported into Geoscan Research's GEOPLOT software (Geoscan Research 2001) for processing. Both shade relief and trace line plots were generated before the instrument's memory was cleared. Upon completion of the survey, the data were processed in GEOPLOT. The grid file was transformed into a composite file and further processed in GEOPLOT. The composite file for the resistance data was first despiked to remove any erroneous measurements. Despiking may be accomplished with the processing routine in GEOPLOT or manually by editing the grid file. The interpolation routine was applied to the data set collected in a 2 x 2 data matrix to arrange the data in an equally spaced 4 x 4 data matrix. A high pass filter was applied to the composite data set to remove low frequency, large scale spatial detail such as a slowing changing geological 'background' trend. The resistance data after despiking ranged from 13.0 ohms to 29.55 ohms with a mean of 24.728 ohms and a standard deviation of 2.083 ohms. The data were then exported as an ASCII *.dat file and placed in the SURFER 8 mapping program. The data were gridded and both an image map (Figure 10) and a contour map were generated for the YELL resistance data.

Conductivity Survey

Instrument: Geonics EM38 electromagnetic conductivity meter (Geonics 1992) with an Omnidata DL-720 polycorder (Geonics 1998)

Specifications: apparent conductivity of the ground in millisiemens per meter (mS/m); measurement precision ±0.1% of full scale deflection; 100 and 1000 mS/m conductivity ranges (4 digit digital meter)

Survey type: conductivity in the quadrature phase component operating mode

Operators: Steven De Vore

The conductivity survey is an active geophysical technique, which induces an electromagnetic field into the ground (see Bevan 1983,1998:29-43; Clark 2000:171; Clay 2001:32-33,2002; Davenport 2001:72-88; David 1995:20; Gaffney and Gater 2003:42-44; Gaffney et al. 1991:5,2002:10; Heimmer and De Vore 1995:35-41,2000:60-63; Kvamme 2001:362-363,2003:441-442,2005:434-436; Lowrie 1997:222-228; McNeill 1980a,1980b; Mussett and Khan 2000:210-219; Scollar et al. 1990:520-590; Sharma 1997:265-308, and Weymouth 1986:317-318,326-327 for more details of conductivity surveys). This survey technique measures the apparent soil conductivity. The present survey is conducted with a Geonics EM38 ground conductivity meter operating in the quadrature phase or conductivity component operating mode (Geonics 1992). The instrument is lightweight and 1.45 meters in length (Figure 11). The self-contained dipole transmitter (primary field source) and self-contained dipole receiver (sensor) coils are located at opposite ends of the meter. The intercoil spacing is 1 meter.

An electromagnetic field is induced into the ground through the transmitting coil. The induced primary field causes an electric current flow in the earth similar to a resistivity survey. In fact, a conductivity survey is the inverse of a resistivity survey. High conductivity equates to low resistivity and vice versa. The materials in the earth create secondary eddy current loops, which are picked up by the instrument's receiving coil. The interaction of the generated eddy loops or electromagnetic field with the earthen materials is directly proportional to terrain conductivity within the influence area of the instrument. The receiving coil detects the response alteration (secondary electromagnetic field) in the primary electromagnetic field. This secondary field is out of phase (quadrature or conductivity phase) with the primary field. The in-phase component of the secondary signal is used to measure the magnetic susceptibility of the subsurface soil matrix. The apparent conductivity data were recorded in units of millisiemens per meter (mS/m). The electrical conductivity unit or siemens is a represents the reciprocal of an ohm-meter (Sheriff 1973:197). The relationship between conductivity and resistivity is represented by the following formula (Bevan 1983; McNeill 1980a): mS/m = 1000/ohm/m.

Changes result from electrical and magnetic properties of the soil matrix. Changes are caused by materials buried in the soil, differences in soil formation processes, or disturbances from natural or cultural modifications to the soil. EM instruments are also sensitive to surface and buried metals. Due to their high conductivity, metals show up as extreme values in the acquired data set. On occasion, these values may be expressed as negative values since the extremely high conductivity signal of the metals cause the secondary coil to become saturated.

In archeology, the instrument has been used to identify areas of compaction and excavation as well as buried metallic objects. It has the potential to identify cultural features that are affected by the water saturation in the soil (Clark 2000; Heimmer and De Vore 1995:35-41). Its application to archeology results from the ability of the instrument to detect lateral changes on a rapid data acquisition, high resolution basis, where observable contrasts exist. Lateral changes in anthropogenic features result from compaction, structural material changes, buried metallic objects, excavation, habitation sites, and other features affecting water saturation (Heimmer and De Vore 1995:37). The conductivity survey can sometimes detect the disturbed soil matrix within the grave shaft. It can also locate large metal objects. Metallic trash on the surface and other small objects buried in the upper portion of the soil can degrade the search of the graves (Bevan 1991:1310).

The meter was connected to the DL720 Polycorder for digital data acquisition (Geonics 1998). The conductivity survey was designed to collect in the continuous or automatic mode with readings collected every 0.25 second resulting in 4 samples per meter. The data were collected in a parallel fashion or unidirectional mode with the surveyor conducting the data acquisition in the same the direction of travel for each traverse across the grid. The data and header files stored in the polycorder were downloaded into the laptop computer at the end of the survey. The survey of the grid unit began in the lower left hand or southwest corner of the grid. The EM38 was used in the quadrature or conductivity phase, the vertical dipole mode, and one orientation parallel to the direction of travel along the traverses. It provided an exploration depth of approximately 1.5 meters with its effective depth around 0.6 meters in the vertical dipole mode. The instrument was nulled and calibrated at before the start of the survey at the same point used to balance and align the fluxgate gradiometer.

The conductivity data were collected at a sampling density of 4 samples per meter along every 0.5 meter traverse or 8 samples per square meter in the geophysical survey area. A total of 863 data measurements were collected during the survey. The data were downloaded to a laptop computer at the end of the survey of the geophysical project. The data were processed using the DAT38W software (Geonics 2002). After the transfer of the data and header files to the laptop computer, the files were automatically converted from the raw EM38 format to DAT38 format with the extension name of G38 (Geonics 2002:12-14). The data were then displayed as data profile lines (Geonics 2002:14-15).

The individual EM38 data file was then converted to XYZ coordinate file in the Surfer data format. To create the XYZ file, the orientation or direction of the survey line was selected in the DAT38W program along with the data type and format (Geonics 2002:20-23). The resulting XYZ data file was transfer to the SURFER 8 mapping software (Golden Software 2002). The conductivity data were reviewed and an image plot was generated in SURFER 8. To further process the conductivity data, it was transferred to GEOPLOT. The conductivity data were stripped of the X and Y coordinates and then the Z values (measurements) were imported into GEOPLOT for further processing (Geoscan Research 2001). The resulting grid was formatted to form a composite file in GEOPLOT. The interpolation routine was applied to the data set to arrange the data in an equally spaced 4 x 4 square matrix. A high pass filter was then applied over the composite data set. The high pass filter was used to remove low frequency, large scale spatial detail such as a slowing changing geological 'background' trend. The data were exported as an ASCII *.dat file and placed in the SURFER 8 mapping program. Finally, the data were presented in an image plot (Figure 12) and a contour plot. The mean for the conductivity data from the project area was 30.000 mS/m with a standard deviation of 8.679 mS/m. The minimum value was -58.5 mS/m and the maximum value was 44.0 mS/m.

Magnetic Susceptibility Survey

Instrument: Geonics EM38 electromagnetic conductivity meter (Geonics 1992) with an Omnidata DL-720 polycorder (Geonics 1998)

Specifications: measured quantity is parts per thousand of the secondary primary magnetic field; operating frequency 14.6 kHz (40.4 kHz); measurement precision ±0.1% of full scale deflection

Survey type: magnetic susceptibility in the in-phase component operating mode

Operator: Steven DeVore

The magnetic susceptibility survey is an active geophysical technique, which induces an electromagnetic field into the ground (see Alexander 1977:368-379; Banerjee 1981:25-99; Challands 1992:33-41; Clark 2000:171; 99-117,175-182; Dalan 1995; Dalan and Banerjee 1998:3-36; David 1995:20-22; Dearing 1994; Dunlop and Özdemir 1997; Ellwood et al. 1998:55-71; Gaffney and Gater 2003:44-46; Gaffney et al. 1991:3,2002:9; Mussett and Khan 2000:139-161; Scollar et al. 1990:375-421; Sharma 1997:65-75; Tarling 1983; Thompson and Oldfield 1986; and Yates 1989 for more details of magnetic susceptibility surveys). Magnetic susceptibility measures the degree to which a material may be magnetized (Sheriff 1973:135). It is defined as the ratio of the induced magnetic field in a material to the applied magnetic field. The present survey is conducted with a Geonics EM38 ground conductivity meter operating in the in-phase component operating mode (Geonics 1992). The instrument is lightweight and 1.45 meters in length. The self-contained dipole transmitter (primary field source) and self-contained dipole receiver (sensor) coils are located at opposite ends of the meter. The intercoil spacing is 1 meter.

An electromagnetic field is induced into the ground through the transmitting coil. The induced primary field causes an electric current flow in the earth. The materials in the earth create secondary eddy current loops, which are picked up by the instrument's receiving coil. The interaction of the generated eddy loops or electromagnetic field with the earthen materials is directly proportional to magnetic susceptibility within the influence area of the instrument. The receiving coil detects the response alteration (secondary electromagnetic field) in the primary electromagnetic field. The in-phase component of the secondary signal is used to measure the magnetic susceptibility of the subsurface soil matrix. It can be expressed as volume susceptibility (K) where the measurement is normalized by volume or as mass susceptibility (X) where the measurement is normalized by mass. Volume susceptibility (K) is equal to the volume magnetization induced in a material of susceptibility (M) divided by an applied field (H). Volume susceptibility is a dimensionless quality (Thompson and Oldfield 1986:25). The magnetic susceptibility value recorded in ppt by the conductivity meter may be converted into K using the formula: $K = 58 \times 10^{-6} \Delta\delta_a$ where $\Delta\delta_a$ is the difference in apparent susceptibility between the measurement on the ground and the measurement when the instrument is elevated to a height of 1.5 meters (Geonics 1992:15). Volume susceptibility is generally used in field surveys where readings are taken with the various field sensors but no samples are collected for further processing in the laboratory setting. The low field mass susceptibility (X) is equal to the volume susceptibility (K) divided by the bulk density of the sample (ρ in units of kg cm^{-3}). This yields X values in the International System's (SI) units of m^3 kg^{-1}. Mass susceptibility is commonly used on collected field samples in a laboratory setting.

Magnetic susceptibility may be one of the most important but least utilized geophysical investigative techniques in archeological landscape studies. Both areal prospection of the surface and the study of the magnetostratigraphy can be employed during a project (Clark 2000:99-117). In general, the technique is extremely sensitive to environmental change and is widely used in environmental studies (Thompson and Oldfield 1986). The techniques for the measurement and interpretation of magnetic susceptibility are derived from the fields of rock magnetism and paleomagnetism (Banerjee 1981; Dearing 1994; Nagata 1961; Tarling 1983). Iron oxides are present in most of the earth's soils. The iron is present and magnetically detectable in grains of magnetite, maghaemite, and hematite. The process of weakly magnetic oxides and hydroxides that are converted to more strongly magnetic forms within the subsurface layers is referred to as "magnetic enhancement." These iron minerals in the soil are "susceptible" to becoming magnetized in the presence of a magnetic field (Ellwood et al. 1998). Enhancement occurs as a function of soil formation and is commonly seen to have higher susceptibility values within the surface layers. The magnetic grains that are produced are typically fine-grained and thus an increase in frequency dependence in conjunction with an increase in susceptibility is potentially indicative of a developed soil (Dalan et al. 2003). This fundamental property can be quickly and easily measured on small samples.

The magnetic susceptibility of soils has a high correlation with the mineralogy of the parent material and local geology. Soils developed in strongly magnetic basalts have higher X values than soils developed in limestone or sandstone. Soils generally have higher X values in the topsoils as compared with the subsoils. Magnetic enhancement of the topsoil results from accumulation of primary minerals that are resistant to weathering found in the parent material (Dearing 1994:48-51) and the formation of secondary minerals by burning of soil in the presence of organic matter, by the addition of dust from industrial combustion processes or volcanic eruptions, and/or by organic and inorganic chemical processes in the soil (Dearing 1994:51-52). The degree of the magnetic enhancement in the topsoil is controlled by the local geology, the climatic conditions, vegetation and organic matter, soil organisms (i.e., bacteria), and time (Alexander 1977:368-379; Dearing 1994:55-61). Human activity also has an effect on the susceptibility through heating effects from fires and chemical and bacterial effects on garbage decomposition (Dearing 1994:88-91). Magnetic enhancement also allows the identification of buried soils, characterization of sediments, and identification of source locations.

The application of magnetic susceptibility to archeological prospection centers around two factors: 1) typically, greater susceptibility is found in the topsoil than in underlying subsoil, and 2) human activities associated with site occupation enhance the susceptibility of the topsoil (Clark 2000:99-17; Gaffney and Gater 2003:44-46). The method has been developed to detect evidence of human occupation and define site limits in the topsoil even when no distinctive features have survived. It can be applied to research questions concerning the following topics: 1) site limits, activity areas, or features; 2) morphology or function of sites, activity areas, and features and their formation processes; 3) the effects of sedimentation and erosion upon the archeological record; 4) establishing and expanding stratigraphic sequences; and 5) climatic regimes and other information on soil-forming factors (Dalan and Banerjee 1998:13). Dalan and Banerjee (1998) provide an overview of the historic and present applications of the techniques to archeological investigations. The magnetic susceptibility studies have been used to study the accumulated cultural and natural deposits (Challands 1992; Yates 1989). These techniques can also be used to correlate stratigraphy across a site, as well as, identify buried soils or paleosols (Dalan and Banerjee 1998).

The present magnetic susceptibility was also conducted with a Geonics EM38 ground conductivity meter. The meter was connected to the DL720 Polycorder for digital data acquisition (Geonics 1998). The magnetic susceptibility survey was designed to collect in the continuous or automatic mode with readings collected every 0.25 second resulting in 4 samples per meter. The magnetic susceptibility survey was designed to collect of 4 samples per meter along every 0.5 meter traverse or 8 samples per square meter in the geophysical survey area. A total of 861 data measurements were collected during the survey. The data file stored in the polycorder was downloaded into the laptop computer at the end of the survey (Geonics 1992,1998). The data were collected in a parallel fashion or unidirectional mode with the surveyor conducting the data acquisition in the same the direction of travel for each traverse across the grid. The survey began in the southwest corner or lower left hand corner of the grid. The EM38 was used in the in-phase mode and the vertical dipole mode with one orientation parallel to the direction of travel along the traverses. It provided an effective exploration depth of approximately

0.5 meters in the vertical dipole mode (Clay 2002). The instrument was nulled and calibrated at the same point used to balance and align the fluxgate gradiometer. The data and header files stored in the polycorder were downloaded into the laptop computer at the end of the survey. The instrument was nulled and calibrated at before the start of the survey at the same point used to balance and align the fluxgate gradiometer.

The data were downloaded to a laptop computer at the end of the survey of the geophysical project area. The data were processed using the DAT38W software (Geonics 2002). Data from each individual grid unit was placed in separate grid data files. The files were then converted from the DL polycorder files to the DAT38W file format. The data were converted to XYZ coordinates in the Geonics DAT38W software. The individual EM38 grid data files were converted to Surfer data files. In SURFER 8 (Golden Software 2002), the magnetic susceptibility data were stripped of its X and Y coordinates and then imported into GEOPLOT for further processing. The grid was transformed into a composite file. The interpolate function was applied to the data to form a 4 x 4 matrix with a sample density of 16 data points per square meter. A high pass filter was finally applied over the composite data set. The high pass filter was used to remove low frequency, large scale spatial detail such as a slowing changing geological 'background' trend. The data were then exported as an ASCII *.dat file and placed in the SURFER 8 mapping program. In SURFER 8, the data are presented in an image plot (Figure 13) and a contour plot. A total of 861 data values was collected during the survey. The mean for the magnetic susceptibility data was 1.246 ppt with a standard deviation of 0.648 ppt. The minimum value was –5.1 ppt and the maximum value was 5.7 ppt.

Ground Penetrating Radar Survey

Instrument: Geophysical Survey Systems Inc. (GSSI) TerraSIRch SIR System-3000 ground penetrating radar cart system with a 400 mHz antenna (GSSI 2003)

Specifications: SIR 3000: System hardware contains a 512 mb compact flash memory card as its internal memory. Accepts industry standard compact flash memory card up to 2 gb. Processor is a 32-bit Intel StrongArm PISC 206 mHz processor with enhanced 8.4" TFT display, 800 x 600 resolution, and 64k colors. The processor also produces linescan and O-scope displays. The gpr system uses one channel. It also uses the GSSI Model 623 survey cart with survey wheel for mounting the antenna and control unit. The 400 mHz Model 5103 ground coupled antenna has a depth of view of approximately 4 m assuming a ground dielectric constant of 8 with a range of 50 ns, 512 samples per scan, 16 bit resolution; 5 gain points, 100 mHz vertical high pass filter, 800 mHz vertical low pass filter, 64 scans per second, and 100 kHz transmit rate.

Survey type: ground penetrating radar

Operator: Steven De Vore

The ground-penetrating radar (gpr) survey is an active geophysical technique (see Bevan 1998:43-57; Clark 2000:118-120,183-185; Conyers 2004; Conyers and Goodman 1997; David 1995:23-27; Gaffney and Gater 2003:74-76; Gaffney et al. 1991:5-6,2002:9-10; Goodman et al. 1995; Heimmer and De Vore 1995:42-47,2000:63-64; Kvamme 2001:363-365,2003:442-443,2005:436-438; Lowrie 1997:221-222; Milsom 2003:131-140; Mussett and Khan 2000:227-231; Scollar et al. 1990:575-584; Sharma 1997:309-329, and Weymouth 1986:370-383 for more details of ground penetrating radar surveys). The gpr unit operated an antenna at a nominal frequency of 400 megahertz (mHz). The antenna was mounted in a cart that recorded the location of the radar unit along the grid line (Figure 14). The gpr profiles were collected along 0.5 meter traverses beginning in the southwest corner of the grid block. The data were collected in a zigzag or bidirectional fashion with the surveyor alternating the direction of travel for each traverse across the grid. A total of 21 radar profiles were collected across the project survey area.

The gpr system transmits a short pulse of high-frequency electromagnetic radio energy or wave into the ground. The receiving portion of the antenna detects the energy that is scattered back by reflecting objects (Sheriff 1973:175). The gpr also measures the elapsed time between the transmission of the pulse, it reflection of a buried object or interface, and the reflection pulse reception on its return to the surface (Conyers and Goodman 1997:1). Reflections may be created by contrasts in electrical (dielectric contrast) properties of the soil matrix or buried archeological objects and features, soil moisture, lithologic differences, bulk density at stratigraphic interfaces, and interfaces between archeological features and the surrounding sediments or soil matrix (Conyers and Goodman 1997:1). Buried voids or air pockets, which are sometimes encountered in graves, tunnels, or caches, generated significant radar reflections caused by the high contrast resulting from the change in the radar wave velocity.

Ground penetrating radar surveys generally represent a trade-off between depth of detection and detail. Lower frequency antennas permit detection of features at greater depths but they cannot resolve objects or strata that are as small as those detectable by higher frequency antennas. Actual maximum depth of detection also depends upon the electrical properties of the soil. If one has an open excavation, one can place a steel rod in the excavation wall at a known depth and use the observed radar reflection to calibrate the radar charts. When it is not possible to place a target at a known depth, one can use values from comparable soils. Reasonable estimates of the velocity of the radar signal in the site's soil can be achieved by this method (Conyers and Lucius 1996). Using one of the hyperbolas on a radargram profile (Goodman 2005:76), the velocity was calculated to be approximately 0.039 cm per nanosecond (ns). For a time slice between 5 and 15 ns with the center at 10 ns (two way travel time), the approximate depth to the center of the gpr slice would be 19.5 cm. With a time window of 100 ns, the gpr profile extended to a depth of 1.95 meters

The survey cart contained a data-logger (SIR 3000) with a display that allowed the results to be viewed almost immediately as they were recorded. The SIR 3000 was set to collect gpr data with the 400 mHz antenna at an antenna transmit rate of 100 mHz and the distance mode selected for use of the survey wheel on the cart. The scan menu was set with 512 samples, 16 bit format, 100 ns range or window, a dielectric constant of 8 (the default value), a scan rate of 100, and 50 scans per meter. In the gain menu, the gain was set to manual with a default value of 3. The gpr system was moved around the grid prior to the start of the survey to adjust the gain. If a location caused the trace wave to go off the screen, the gain was set to auto and then back to manual. The position was set to the manual mode with the offset value at the factory default and the surface display option set to zero. The filters were left at the default settings. With the setup completed, the run/stop button at the bottom of the display screen was selected and the collect mode was initiated. The gpr unit was moved across the grid and at the end of the traverse, the next file button was selected and data acquisition was halted. The gpr unit was placed at the start of the next line before saving the profile. Once the profile data was saved, the gpr unit was ready to collect the next profile line. The gpr data were recorded on a 512 mb compact flash card and transferred to a lap-top computer at the end of the survey.

The gpr radargram profile line data are imported into GPR-SLICE (Goodman 2005) for processing. The first step in GPR-SLICE is to create a new survey project under the file menu. This step identifies the file name and folder locations. The next step is to create the information file. The number of profiles are entered, along with the file identifier name, .dzt for GSSI radargrams, the profile naming increment of 1, the first radargram name (generally this is 1), direction of profiling, x and y beginning and ending coordinates, units per marker (set to 1), the time window opening in nanoseconds (100 ns), samples per scan (512 s/scn), the number of scans per meter (these profiles were collected at 50 scans per meter), type of data (16 bit). Selecting the create info file button completes the information file for the project. The information file can be edited if necessary to correct profile lengths. The 16-bit GSSI radargrams are imported into the GPR-SLICE project folder for further processing. The 16-bit data are then converted to remove extraneous header information and to regain the data. During the conversion process, the signal is enhanced by applying gain to the radargrams. Once the conversion process is completed, the next step is to reverse the profile data. Since the radargrams were collected in the zigzag mode, every even line needs to be reversed. The reverse map button shows the radargrams that are going to be reversed. The next step is to insert navigation markers into the resample radargrams. The GSSI SIR 3000 and the artificial markers button are selected to apply markers based on the total number of scans in the radargram. The show markers button allows one to view an example of a radargram with the artificial markers in place. The next step is to create the time slices of the profile data (Conyers and Goodman 1997; Goodman et al. 1995). The program resamples the radargrams to a constant number of scans between the markers and collects the time slice information from the individual radargrams. The number of slices is set to 20 slices. The slice thickness is set to 30 to allow for adequate overlap between the slices. The offset value on the radargram where the first ground reflection occurs is viewed in the search 0 ns subroutine. This value is used to identify the first radargram sample at the ground surface. The end sample is 512. The offset value in entered in the samples to 0 ns box. The cut parameter is set to square amplitude with the cuts per mark set to 4. The slice/resample button is selected for processing the radargrams. The final step in the slice menu is to create the XYZ data file. The grid menu is entered next in the processing steps. The beginning and ending values for the x and y coordinate are entered. The help set button is selected to set the x search radius, y search radius and the blanking radius. The grid cell size is set to 0.1 and the search type is rectangular. The number of grids equal 20 for the number of slices, and the starting grid number is 1. The Kriging algorithm is utilized to estimate the interpolated data. The Varigram button is selected to set the Kriging range, nugget and sill parameters. The start gridding button is selected and the gridded dataset is created. In this menu, a low pass filter may be applied to the dataset to smooth noisy data in the time slices. At this point, one may view the time sliced radar data in the pixel map menu (Figure 15). In addition, the original processed grid slices and the low pass filtered grid slices can be exported in the Surfer grid format. The surfer grid file is transformed into an image plot in Surfer. Generally, one time slice is selected for further display and analysis. Time slice 5 (Figure 16) was selected from the geophysical project area for further analysis. The gain may be readjusted for any time slice. This is done in the transforms submenu. The interpolations value is set to 5 and the interpolate grids routine is selected. The new interpolated grids are all normalized. The next step is to create the 3D dataset in the grid menu. The number of grids is now equal to 95 ((20-1)*5). The 3D database is created under the create 3D file routine. The 3D data may be displayed as a series of z slices in the creation of a 3D cube with a jpeg output for animating the 3D cube.

Interpretations

Andrew David (1995:30) defines interpretation as a "holistic process and its outcome should represent the combined influence of several factors, being arrived at through consultation with others where necessary." Interpretation may be divided into two different types consisting of the geophysical interpretation of the data and the archaeological interpretation of the data. At a simplistic level, geophysical interpretation involves the identification of the factors causing changes in the geophysical data. Archeological interpretation takes the geophysical results and tries to apply cultural attributes or causes. In both cases, interpretation requires both experience with the operation of geophysical equipment, data processing, and archeological methodology; and knowledge of the geophysical techniques and properties, as well as known and expected archeology. Although there is variation between sites, several factors should be considered in the interpretation of the geophysical data. These may be divided between natural factors, such as geology, soil type, geomorphology, climate, surface conditions, topography, soil magnetic susceptibility, seasonality, and cultural factors including known and inferred archeology, landscape history, survey methodology, data treatment, modern interference, etc. (David 1995:30). It should also be pointed out that refinements in the geophysical interpretations are dependent on the feedback from subsequent archeological investigations. The use of multiple instrument surveys provides the archeologist with very different sources of data that may provide complementary information for comparison of the nature and cause (i.e., natural or cultural) of a geophysical anomaly (Clay 2001). Each instrument responds primarily to a single physical property: magnetometry to soil magnetism, electromagnetic induction to soil conductivity, resistivity to soil resistance, and ground penetrating radar to dielectric properties of the soil to (Weymouth 1986:371).

The magnetic gradient data reveal three major clusters of magnetic dipole anomalies. The largest cluster is located over the area of suspected grave as identified by the alignment of stone cobbles (Figure 17). The strength of the anomalies suggest the presence of buried iron based materials similar to the sheet metal that was removed before the start of the geophysical survey and other iron based artifacts or materials. Two linear magnetic anomalies are located in the southern half of the survey grid. These may represent erosional features present at or near the ground surface.

The resistance survey data indicate an area of high resist in the immediate vicinity of the stone cobble outline (Figure 18). The area is roughly rectangular in shape and measures approximately 4 by 3 meters. Other relatively high resistance areas are located to the southeast and southwest of the one identified on the image plot. A smaller high resistance area is located in the northwest corner of the grid. Due to the close proximity of the park's open air maintenance storage area, it is possible that these anomalies represent construction related materials or discarded items. The other areas do not have the regular shape identified with the first area suggesting that they have a natural origin.

The conductivity data provide additional clarification on the nature of the magnetic anomalies (Figure 19). The conductivity anomaly in the north central part of the grid corresponds to the large magnetic dipole cluster. This positive relationship indicates the presence of buried or near surface iron based material similar to the sheet metal that was removed before the start of the survey. The conductivity anomaly to the northeast of the central anomaly may also be some form of iron based material although the anomaly does not coincide with the magnetic anomaly. A smaller conductivity anomaly to the east of the large conductivity anomaly appears to coincide with the eastern portion of the cluster of magnetic anomalies in the same general location. This conductivity anomaly would appear to represent some form of iron based artifact or material. Although a square area of relatively high conductivity exists near the magnetic anomaly centered near N4.5/E2, the conductivity anomaly does not have the strong signature of a metal object suggesting that the magnetic anomaly may be fired clay (i.e., a brick of pile of bricks) or magnetic rock. The linear conductivity anomaly near the south center of the grid corresponds to the linear magnetic anomaly in the same location. Since the conductivity anomaly lacks the high contrast found with metal pipe, it would appear that the anomaly represents an erosional feature as suggested with the linear magnetic anomaly.

The magnetic susceptibility data reveal a strong cluster of magnetic susceptibility anomalies in the same general area identified for the strong magnetic and strong conductivity anomaly clusters (Figure 20). These clusters lie along the northwestern edge of the stone cobbles suspected of outlining the possible historic grave. A less intense susceptibility anomaly is located to the northeast of the large cluster. It also coincides with the magnetic and conductivity clusters in this location. Two linear susceptibility anomalies of moderate contrast with the background are in the same location as the two linear magnetic anomalies and the one corresponding linear conductivity anomaly. As indicated in the discussion of the magnetic and conductivity anomalies, these anomalous areas probably represent erosional features.

Time slice 5 (Figure 21) was selected as the representative ground penetrating data set for analysis. Slice 5 was between 18.2 and 24 nanoseconds (two way travel time of the radar signal). The slice represented an approximate 11 cm thick slice between 35.5 cm and 46.8 cm deep. A few extremely high amplitude strength anomalies were present in the data set including one at the northwest corner of a weaker square shaped gpr anomalous area. Given the square anomaly's approximate location adjacent to the surface outline of stone cobbles, the shape and depth of the anomaly strongly suggested that it represented the location of the suspected 19th century historic grave.

Conclusions

During end of May and beginning of June 2005, the Midwest Archeological Center archeologist conducted geophysical investigations at a suspected 19th century grave location near the northern boundary of Yellowstone National Park in Park County, Montana. Located on the outskirts of the gateway community of Gardiner Montana, the project area was located adjacent to the park's outdoor maintenance storage area northwest of the park's Heritage and Research Center. The geophysical survey was conducted at the request of the Yellowstone National Park archeologist to provide additional information on the nature of the suspected grave location. The geophysical investigations included a magnetic gradient survey with a fluxgate gradiometer, a resistance survey with a resistance meter and twin probe array, a conductivity survey and a magnetic susceptibility survey with a ground conductivity meter, and a ground penetrating radar survey with a ground penetrating radar cart system and 400 mHz antenna. A total of 100 square meters or 0.025 acres were surveyed with the geophysical instruments. The geophysical survey of the suspected grave location resulted in the identification of a number of strong contrast subsurface anomalies in the general vicinity of the surface, stone cobble alignment. Although the data did not definitively identify the grave location, the complimentary lines of evidence from the analysis of the five geophysical data sets strongly suggest the presence of the grave in the north central part of the survey area.

Additional geophysical investigations utilizing downhole magnetic susceptibility equipment should be used at the suspected grave location due to the lack of a definitive grave identification. Although the geophysical techniques represent extremely valuable methodologies for the initial investigation of cemeteries and unmarked grave locations, it may necessary to verify the identified anomalies as the grave location through more traditional methods of archeological excavation. However, geophysical techniques provide the best initial evaluative phase of cemetery and isolated grave investigations where eminent destruction of the grave(s) is not at issue. There may be a need for follow up archeological excavations or ground truthing to verify the geophysical anomalies identified during the survey efforts. These excavations can be more efficiently planned with the geophysical background data than through the use of traditional archeological excavation strategies in extremely cultural sensitive areas such as cemeteries and isolated, unmarked graves.

This report has provided a cursory review and analysis of the geophysical data collected during the geophysical investigations of the suspected grave location northwest of the Heritage Center. This information may be used by the park staff to consult with the State Historic Preservation Officer about the impact of the park related activities in the vicinity of the isolated and unmarked grave. This information may also be used by the Midwest Archeological Center and the Yellowstone National Park staffs to guide further archeological inquiry into the nature of the site.

References Cited

Alexander, Martin

1977 *Introduction to Soil Microbiology.* Second Edition. John Wiley and Sons, New York.

Banerjee, Subir K.

1981 Experimental Methods of Rock Magnetism and Paleomagnetism. In *Advances in Geophysics*, Volume 23, edited by Barry Saltzman. pp. 25-99. Academic Press, New York.

Bevan, Bruce W.

1983 Electromagnetics for Mapping Buried Features. *Journal of Field Archaeology* 10(1):47-54.

1991 The Search for Graves. *Geophysics* 56(9):1310-1319.

1998 *Geophysical Exploration for Archaeology: An Introduction to Geophysical Exploration*. Special Report No. 1. Midwest Archeological Center, Lincoln, Nebraska.

Challands, Adrian

1992 Field Magnetic Susceptibility Measurement for Prospection and Excavation. In *Geoprospection in the Archeological Landscape*, edited by Paul Spoerry, pp. 33-41. Oxbow Monograph 18. Oxbow Books, Oxford, Great Britain.

Clark, Anthony

2000 *Seeing beneath the Soil: Prospecting Methods in Archaeology*. Reprint. Routledge, London. Originally published in 1996 by B. T. Batsford Ltd., London.

Clay , R. Berle

2001 Complementary Geophysical Survey Techniques: Why Two Ways are always Better than One. *Southeastern Archaeology* 20(1):31-43.

2002 Conductivity (EM) Survey: A Survival Manual. Ms. on file, Cultural Resource Analysts, Inc., Lexington, Kentucky.

Conyers, Lawrence B.

2004 *Ground-Penetrating Radar for Archaeology*. AltaMira Press, Walnut Creek, California.

Conyers, Lawrence B., and Dean Goodman

1997 *Ground-Penetrating Radar: An Introduction for Archaeologists*. AltaMira Press, Walnut Creek, California.

Conyers, Lawrence B., and Jeffrey E. Lucius
1996 Velocity Analysis in Archaeological Ground-penetrating Radar Studies. *Archaeological Prospection* 3(1):25-38.

Dalan, Rinita A.
1995 Geophysical Surveys for Archaeological Research: Electromagnetic Conductivity Surveys. Ms. on file, Midwest Archeological Center, National Park Service, Lincoln, Nebraska. <http://www.cast.uark.edu/nadag/EducationalMaterials/EM/Dalan1.pdf>.

Dalan, Rinita A., and Subir K. Banerjee
1998 Solving Archaeological Problems Using Techniques of Soil Magnetism. *Geoarchaeology* 13(1):3-36.

Davenport, G. Clark
2001 *Where is it? Searching for Buried Bodies & Hidden Evidence*. SportWork, Church Hill, Maryland.

David, Andrew
1995 *Geophysical Survey in Archaeological Field Evaluation*. Research & Professional Services Guidelines No. 1. English Heritage, Swindon, England.

Dearing, John
1994 *Environmental Magnetic Susceptibility: Using the Bartington MS2 System*. Bartington Instruments Ltd., Oxford, England.

Dice, Lee R.
1943 *The Biotic Provinces of North America*. University of Michigan Press, Ann Arbor.

Dunlop, David J., and Özden Özdemir
1997 *Rock Magnetism: Fundamentals and Frontiers*. Cambridge University Press, Cambridge, United Kingdom.

Ellwood, Brooks B., João Zilhão, Francis, B. Harrold, William Balsam, Burke Burkart, Gary J. Long, André Debénath, and Abdeljalil Bouzouggar
1998 Identification of the Last Glacial Maximum in the Upper Paleolithic of Portugal Using Magnetic Susceptibility Measurements of Caldeirão Cave Sediments. *Geoarchaeology* 13(1):55-71.

Fenneman, Nevin M.
1931 *Physiography of Western United States*. McGraw-Hill Book Company, New York.

Gaffney, Chris, and John Gater
2003 *Revealing the Buried Past: Geophysics for Archaeologists*. Tempus, Stroud, Great Britain.

Gaffney, Chris, John Gater, and Sue Ovenden
1991 *The Use of Geophysical Techniques in Archaeological Evaluations*. Technical Paper Number 9. Institute of Field Archaeologists, University of Birmingham, Birmingham, England.
2002 *The Use of Geophysical Techniques in Archaeological Evaluations*. IFA Paper No. 6. Institute of Field Archaeologists, University of Birmingham, Birmingham, England.

Geonics
1992 *EM38 Ground Conductivity Meter Operating Manual for EM38 Models with Digital Readout*. Geonics Limited, Mississauga, Ontario, Canada.
1998 DL720/38 Data Logging System Operating Instructions for EM38 Ground Conductivity Meter with Polycorder Series 720, Version 3.40. Geonics Limited, Mississauga, Ontario, Canada.
2002 *DAT38W Version 1.10 Computer Program Manual (Survey Data Reduction Manual)*. Geonics Limited, Mississauga, Canada.

Geoscan Research
1987 *Fluxgate Gradiometer FM9 FM18 FM36 Instruction Manual, Version 1.0*. Geoscan Research, Bradford, England.
1996 *Resistance Meter RM15 Instruction Manual, Version 2.4*. Geoscan Research, Bradford, England.
2001 *Geoplot Version 3.00 for Windows Instruction Manual, Version 1.6*. Geoscan Research, Bradford, England.

Golden Software
2002 *Surfer 8 User's Guide: Contouring and 3D Surface Mapping for Scientists and Engineers*. Golden Software, Golden, Colorado.

Goodman, Dean
2005 *GPR-SLICE – Ground Penetrating Radar Imaging Software Quickstart Users Manual, Ver. 5.0*. Geophysical Archaeometry Laboratory, Woodland Hills, California.

Goodman, D., Y. Nishimura, and J. D. Rogers
1995 GPR Time Slices in Archaeological Prospection. *Archaeological Prospection* 2(2):85-89.

GSSI
2003 *TerraSIRch SIR System-3000 User's Manual*. Geophysical Survey Systems, Inc., North Salem, New Hampshire.

Heimmer, Don H., and Steven L. De Vore

1995 *Near-Surface, High Resolution Geophysical Methods for Cultural Resource Management and Archeological Investigations*. Revised Edition. National Park Service, Denver.

2000 Near-Surface, High Resolution Geophysical Methods for Cultural Resource Management and Archeological Investigations. In *Science and Technology in Historic Preservation*, edited by Ray A. Williamson and Paul R, Nickens, pp. 53-73. Advances in Archaeological and Museum Science Volume 4. Kluwer Academic/Plenium Publishers, New York.

Kvamme, Kenneth L.

2001 Current Practices in Archaeogeophysics: Magnetic, Resistivity, Conductivity, and Ground-Penetrating Radar. In *Earth Sciences and Archaeology*, edited by Paul Goldberg, Vance T. Holliday, and C. Reid Ferring, pp. 353-384. Kluwer Academic/Plenium Publishers, New York.

2003 Geophysical Surveys as Landscape Archaeology. *American Antiquity* 68(3):435-457.

2005 Terrestrial Remote Sensing in Archaeology. In *Handbook of Archaeological Methods*, edited by Herbert D. G. Maschner and Christopher Chippindale, pp. 423-477. AltaMira Press, Lanham, Maryland.

Lowrie, William

1997 *Fundamentals of Geophysics*. Cambridge University Press, Cambridge, United Kingdom.

McNeill, J. Duncan

1980a *Electrical Conductivity of Soils and Rocks*. Technical Note TN-5. Geonics Limited, Mississauga, Canada.

1980b *Electromagnetic Terrain Conductivity Measurements at Low Induction Numbers*. Technical Note TN-6. Geonics Limited, Mississauga, Canada.

Milsom, John

2003 *Field Geophysics*. Third Edition. John Wiley & Sons, Chichester, United Kingdom.

Mussett, Alan E., and M. Aftab Khan

2000 *Looking into the Earth: An Introduction to Geological Geophysics*. Cambridge University Press, Cambridge, United Kingdom.

Nagata, Takesi

1961 *Rock Magnetism*. Revised Edition. Maruzen Company Ltd., Tokyo.

Rodman, Ann, Henry Shovic, and David Thoma

1996 *Soils of Yellowstone National Park*. Yellowstone Center for Resources, Yellowstone National Park, Wyoming.

Scollar, I., A. Tabbagh, A. Hesse, and I. Herzog
1990 *Archaeological Prospection and Remote Sensing*. Topics in Remote Sensing 2. Cambridge University Press, Cambridge, Great Britain.

Sharma, Prem V.
1997 *Environmental and Engineering Geophysics*. Cambridge University Press, Cambridge, United Kingdom.

Sheriff, Robert E.
1973 *Encyclopedic Dictionary of Exploration Geophysics*. Society of Exploration Geophysicists, Tulsa, Oklahoma.

Tarling, D. H.
1983 *Paleomagnetism: Principles and Applications in Geology, Geophysics, and Archaeology*. Chapman and Hall, London.

Thompson, Ray, and Frank Oldfield
1986 *Environmental Magnetism*. Allen & Unwin, London.

Trimble
1999 *GeoExplorer 3 Operation Guide*. Trimble Navigation Limited, Sunnyvale, California.

Ushikata
2005 *Tracon & Surveying Compasses Operation Manual*. Ushikita Mfg. Co., Ltd., Tokyo, Japan.

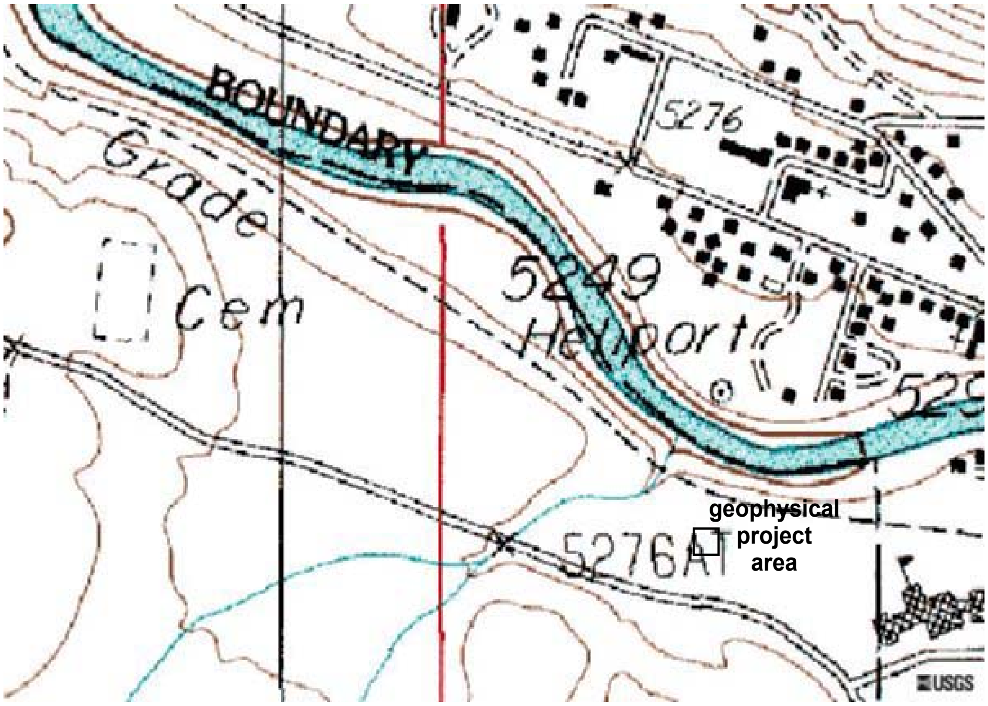
Walker, Danny, and Elaine Skinner Hale
2004 Notes on Auger Tests on Edges of Heritage Center (Possible) Burials – May 17, 2004. Ms. on file, Yellowstone National Park, Wyoming.

Weymouth, John W.
1986 Geophysical Methods for Archaeological Site Surveying. In *Advances in Archaeological Method and Theory, Volume 9*, edited by Michael B. Schiffer, pp. 311-395. Academic Press, Orlando, Florida.

Whittlesey, Lee H.
2003 They're Going to Build a Railroad: Cinnabar and the Gardiner Addition to Yellowstone National Park. Ms. on file, Yellowstone National Park, Wyoming.

Yates, G.
1989 Environmental Magnetism Applied to Archaeology. Unpublished Ph.D. thesis, University of Liverpool, Liverpool, England

Figures



a) 1 km SW of Gardiner, Montana, United States (USGS topographic map dated 01 July 1986).

b) 1 km SW of Gardiner, Montana, United States (USGS aerial photograph dated 03 September 1991).

Figure 1. Location of the project area within Yellowstone National Park, Park County, Montana.

Figure 2. General view of the suspected grave location (view to the west southeast).

Figure 3. Grave location after the removal of the snow fence (view to the southeast).

Figure 4. Survey ropes over the geophysical project area (view to the north).

Figure 5. Making a sketch map of the suspected grave within the geophysical project area (view to the west).

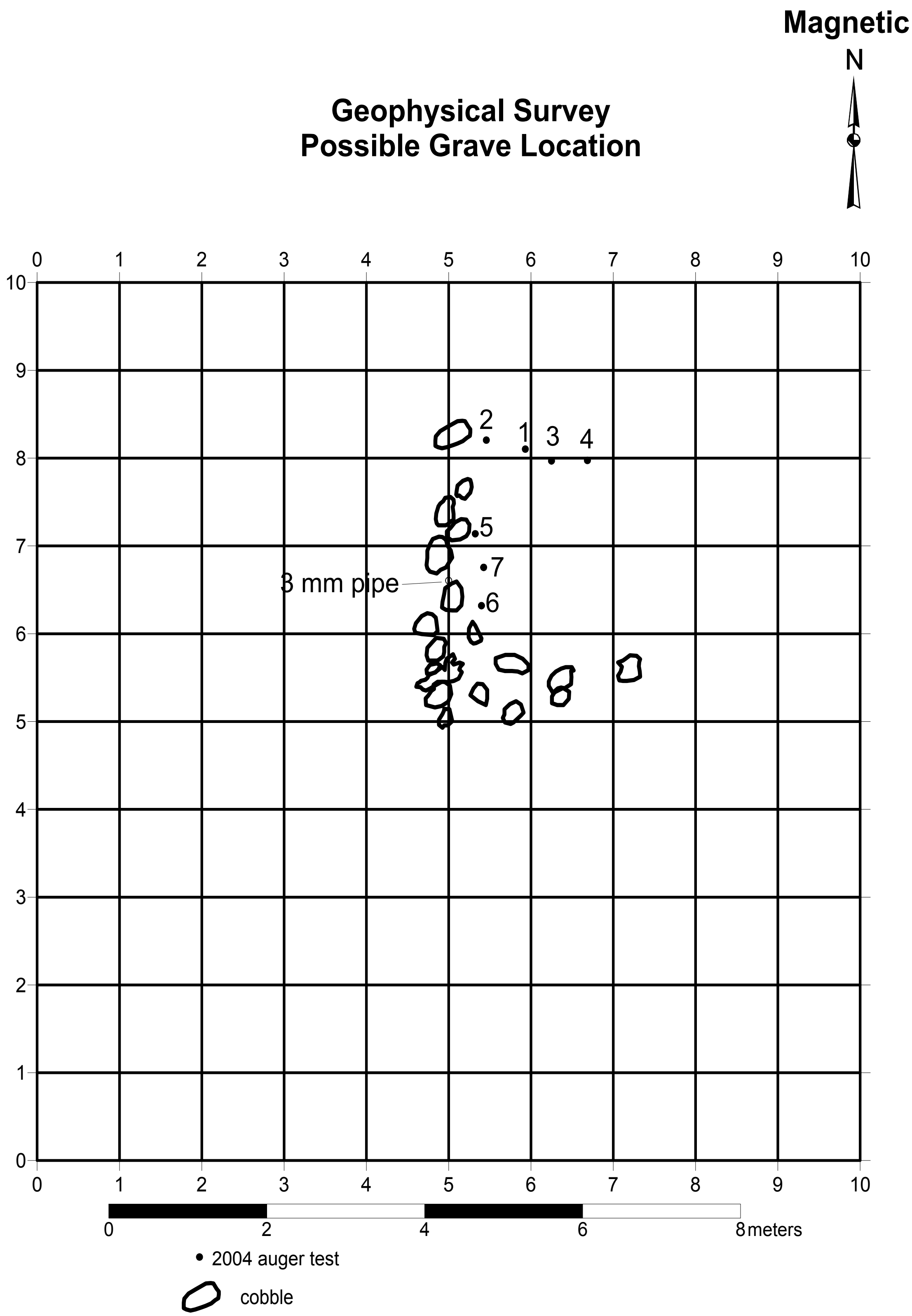


Figure 6. Sketch of cobble stones outlining the suspected grave and the 2004 auger test locations within the geophysical grid.

Figure 7. Conducting magnetic gradient survey with fluxgate gradiometer (view to the southwest).

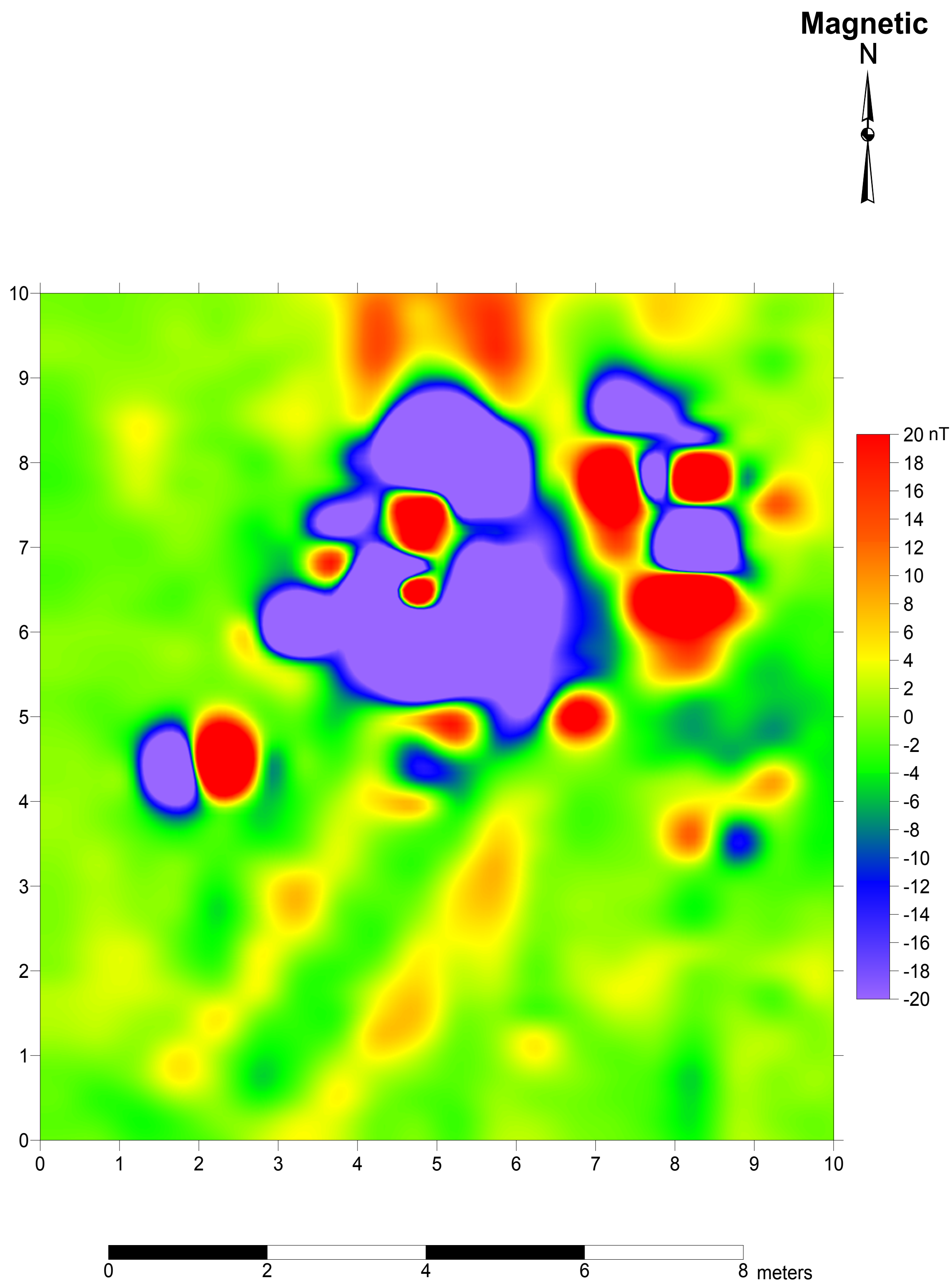


Figure 8. Image plot of magnetic gradient data from the suspected grave location.

Figure 9. Conducting the resistance survey with the resistance meter and twin probe array (view to the east).

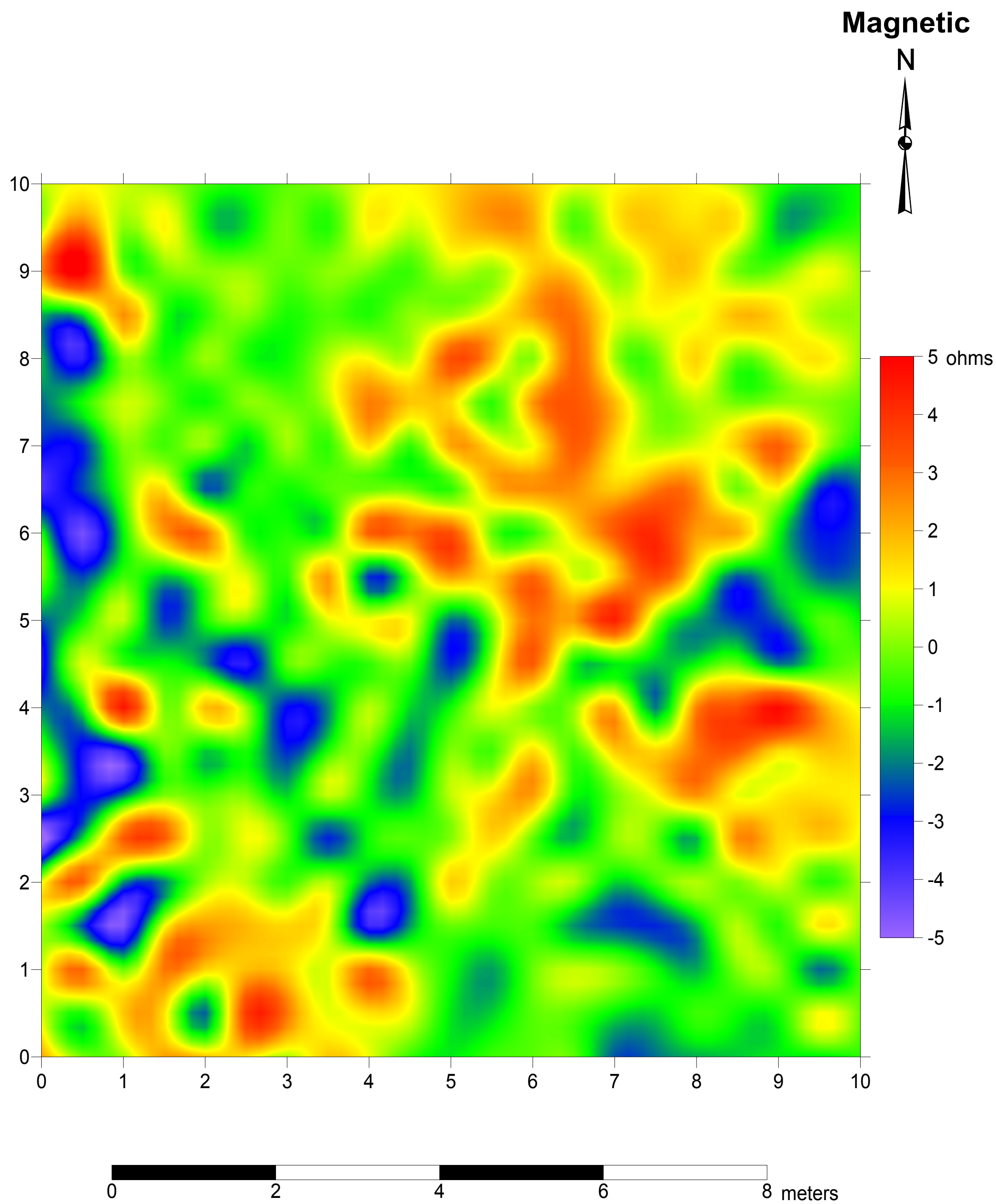


Figure 10. Image plot of resistance data from the suspected grave location.

Figure 11. Conducting the conductivity survey with the ground conductivity meter (view to the southwest).

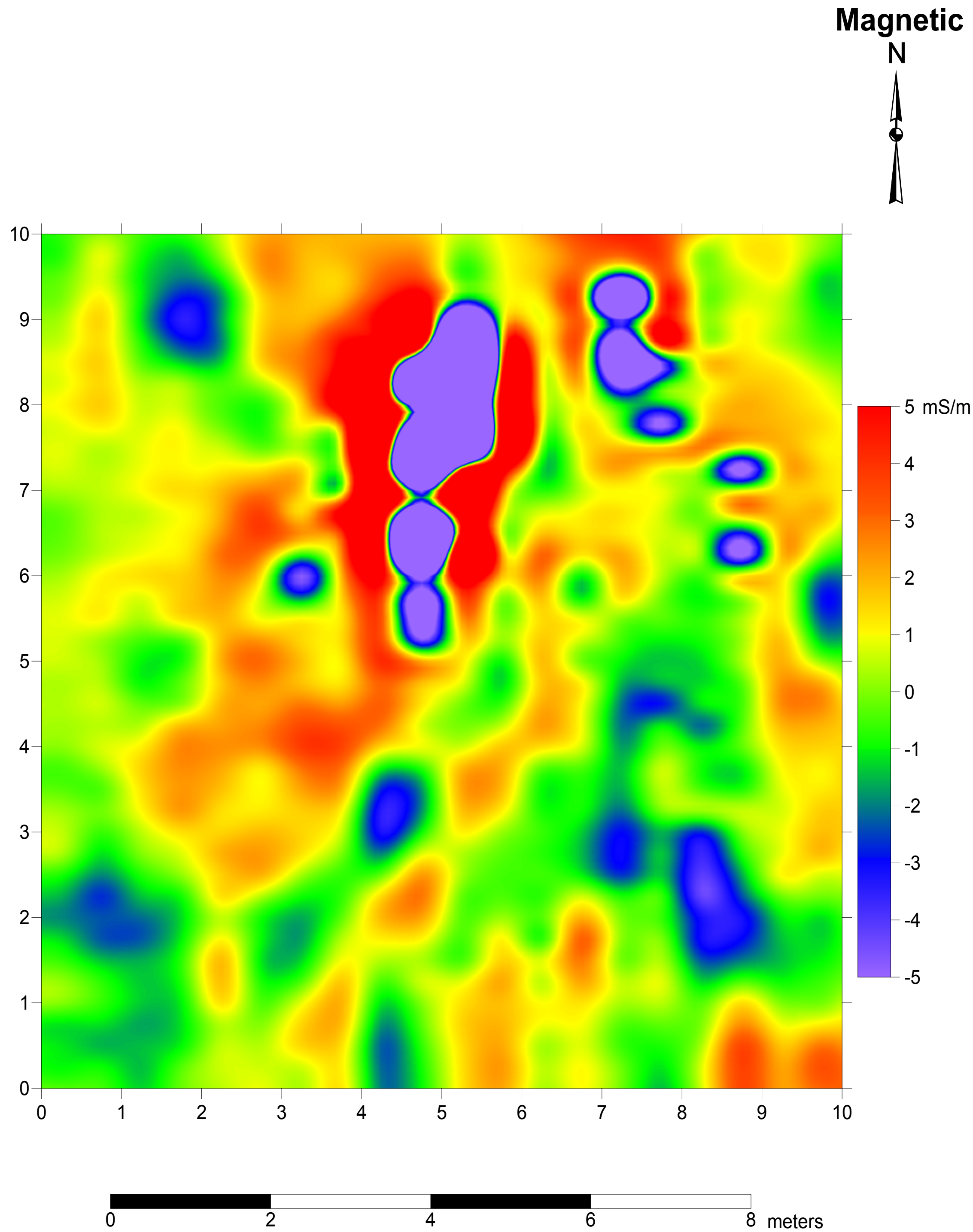


Figure 12. Image plot of conductivity data from the suspected grave location.

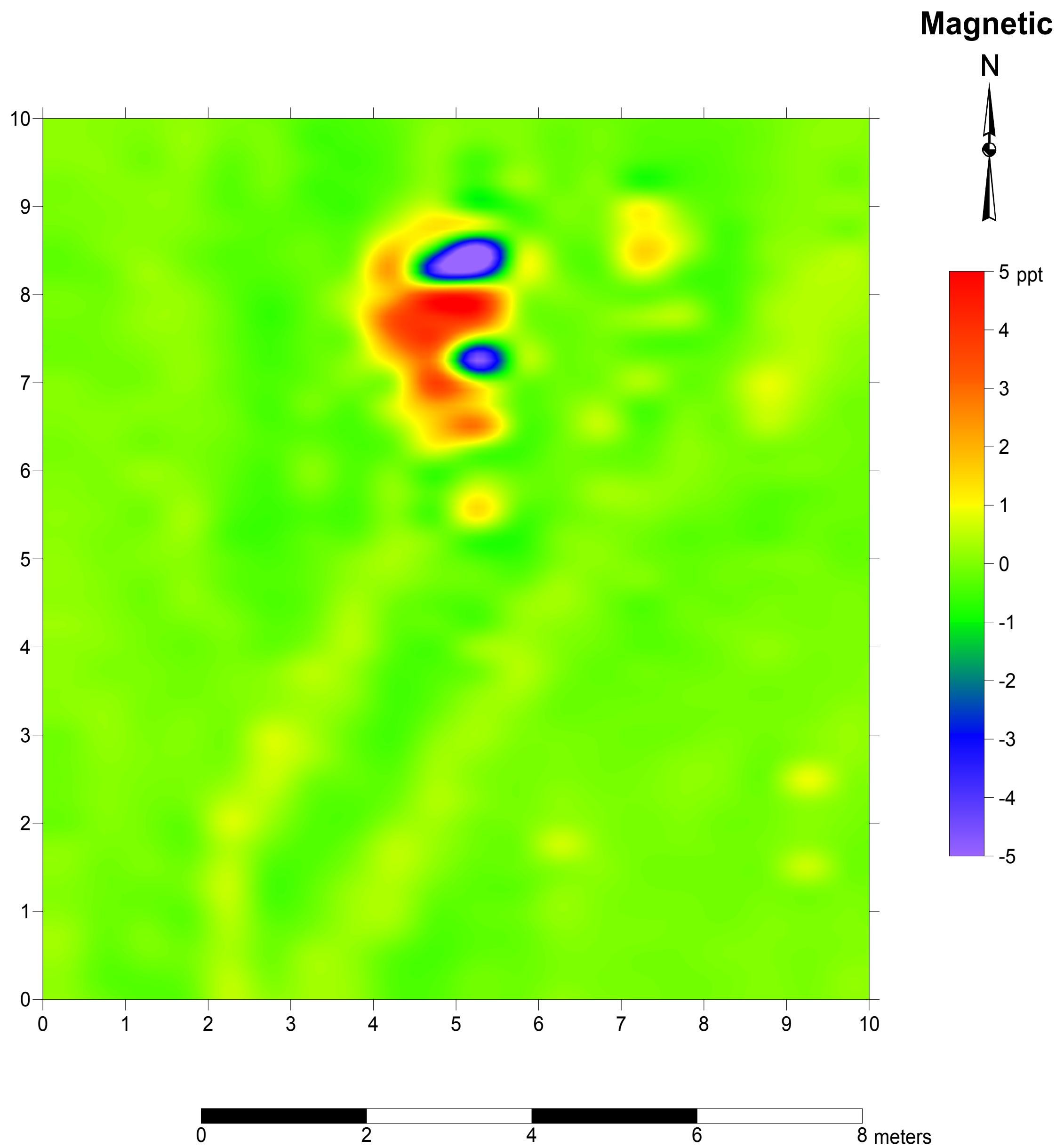


Figure 13. Image plot of magnetic susceptibility data from the suspected grave location.

Figure 14. Conducting ground penetrating radar survey with gpr cart system and 400 mHz antenna (view to the southeast).

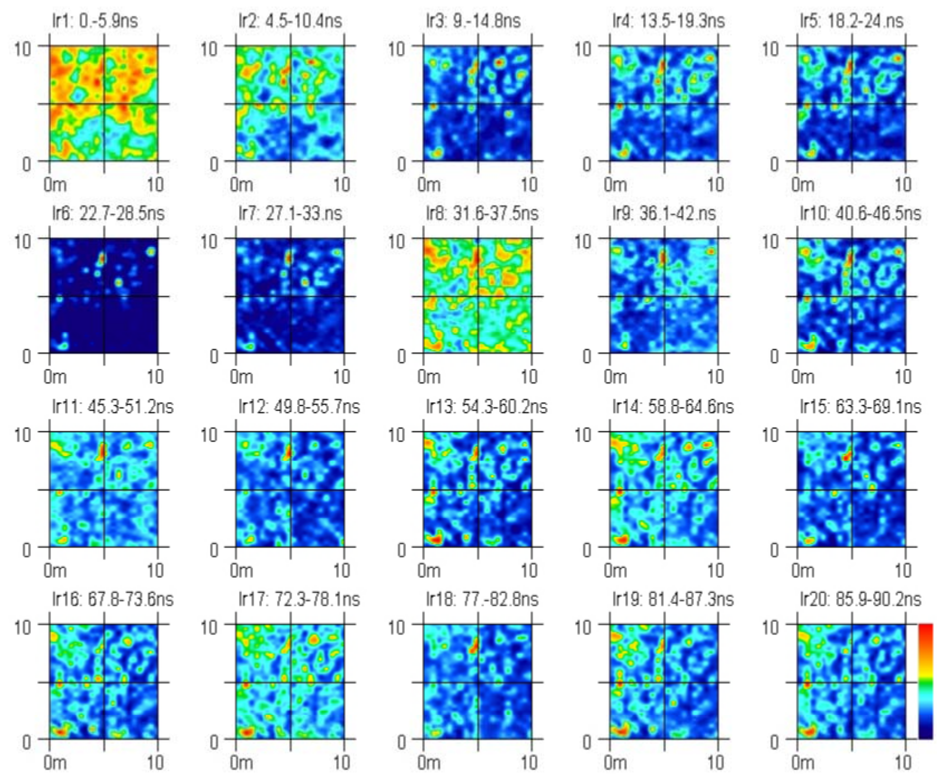


Figure 15. Time slices of ground penetrating radar data from the suspected grave location.

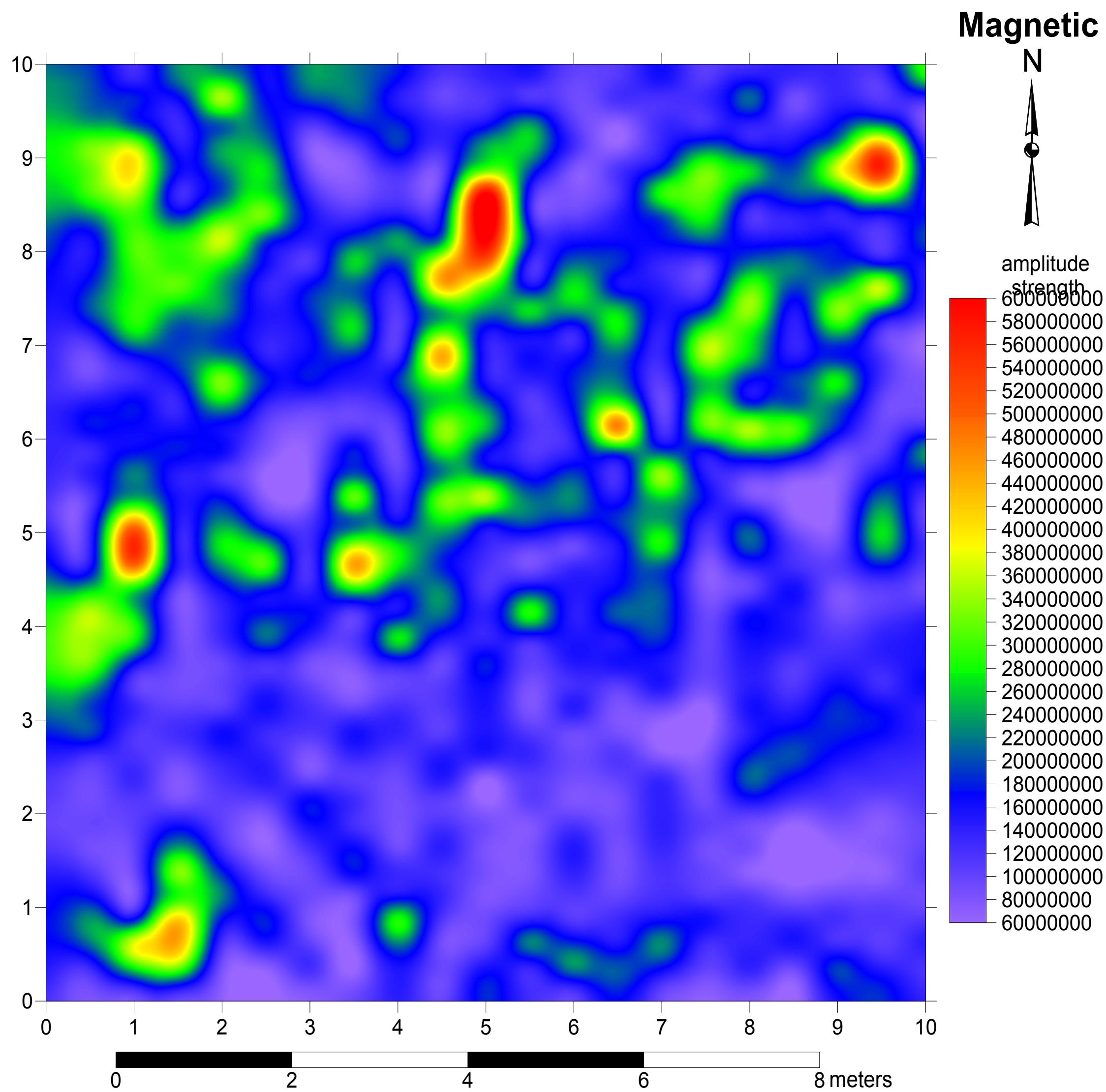


Figure 16. Image plot of time slice 5 data from the suspected grave location.

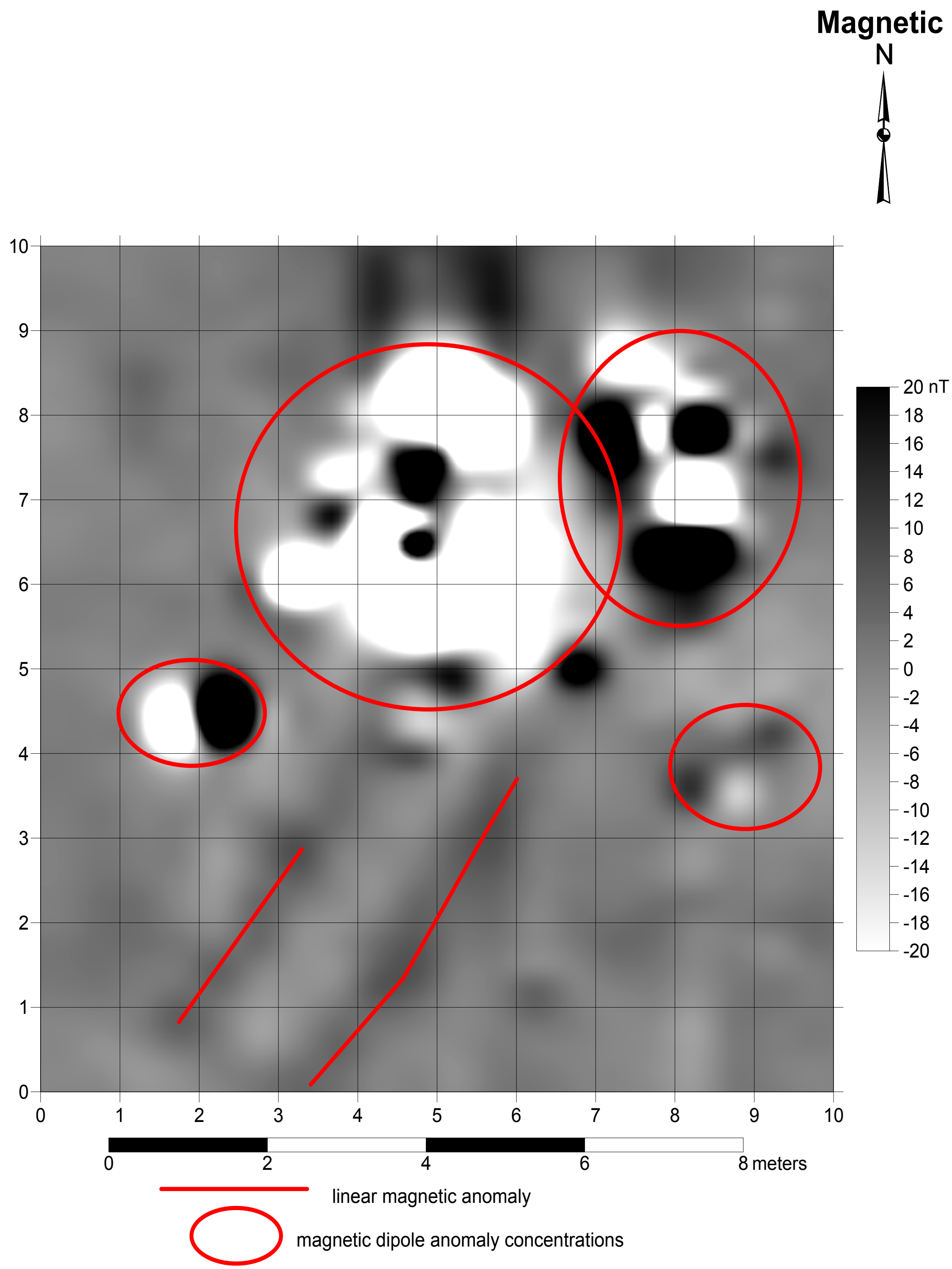


Figure 17. Interpretative map of magnetic gradient data from the suspected grave location.

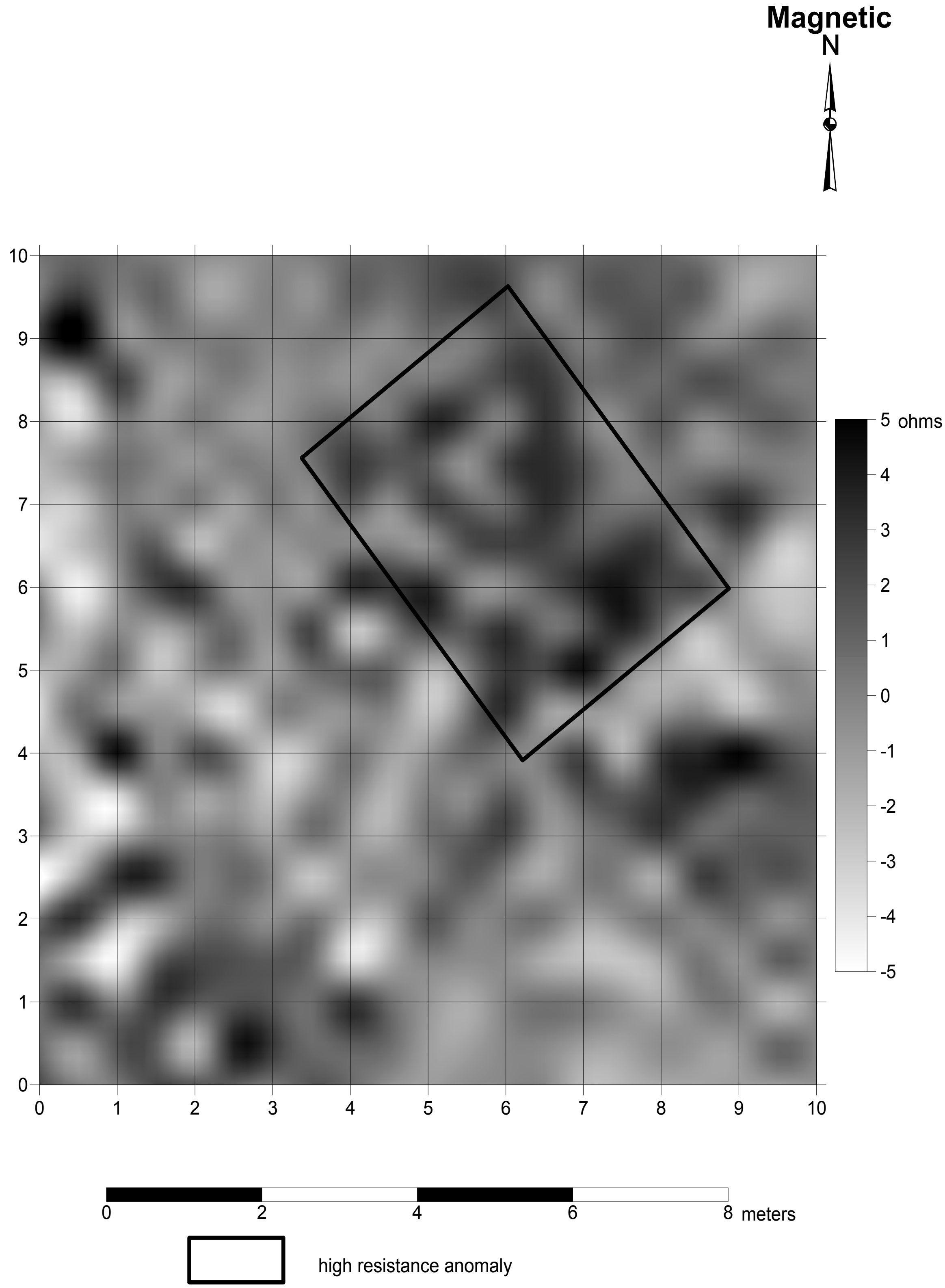


Figure 18. Interpretative map of resistance data from the suspected grave location.

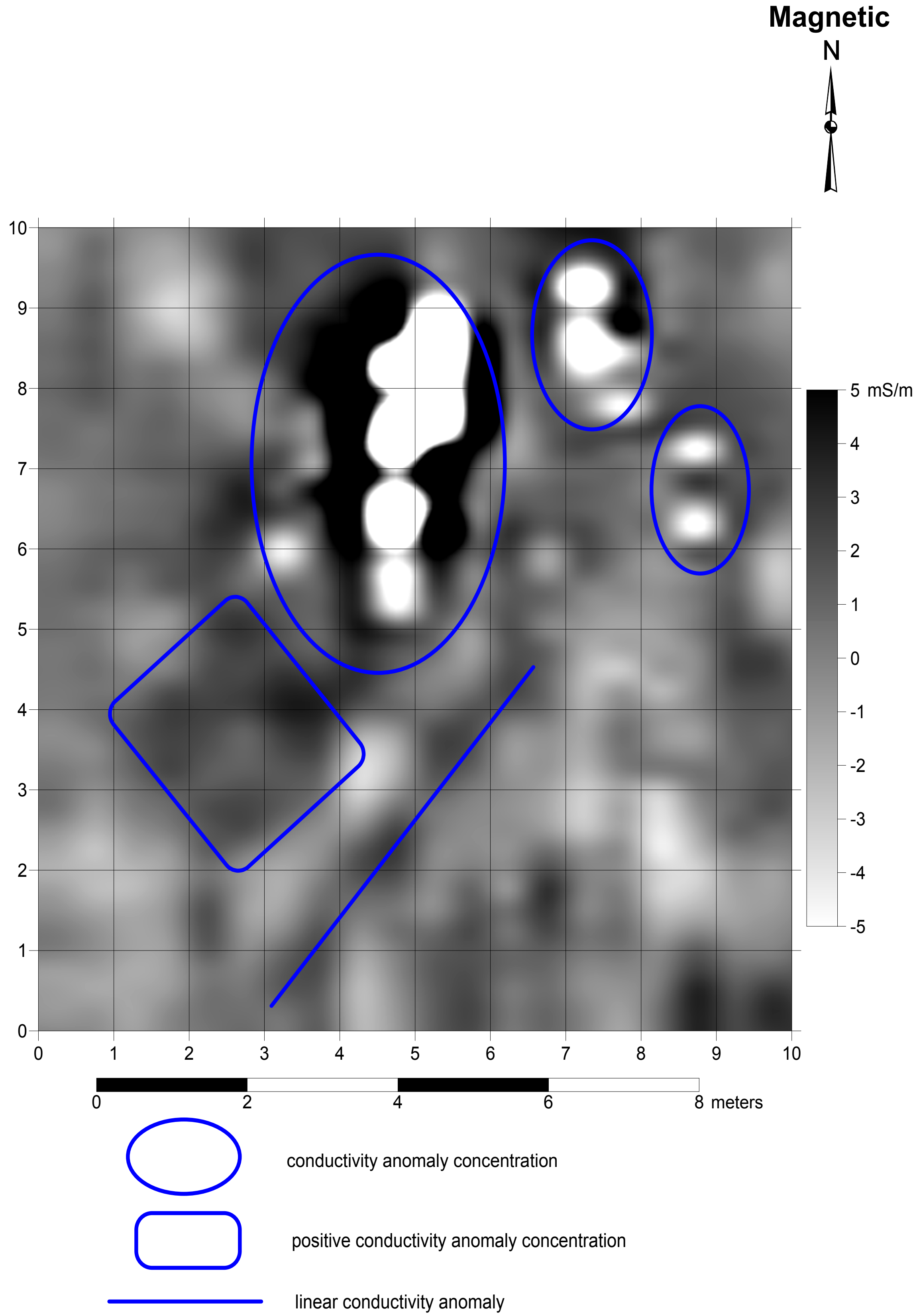


Figure 19. Interpretative map of conductivity data from the suspected grave location.

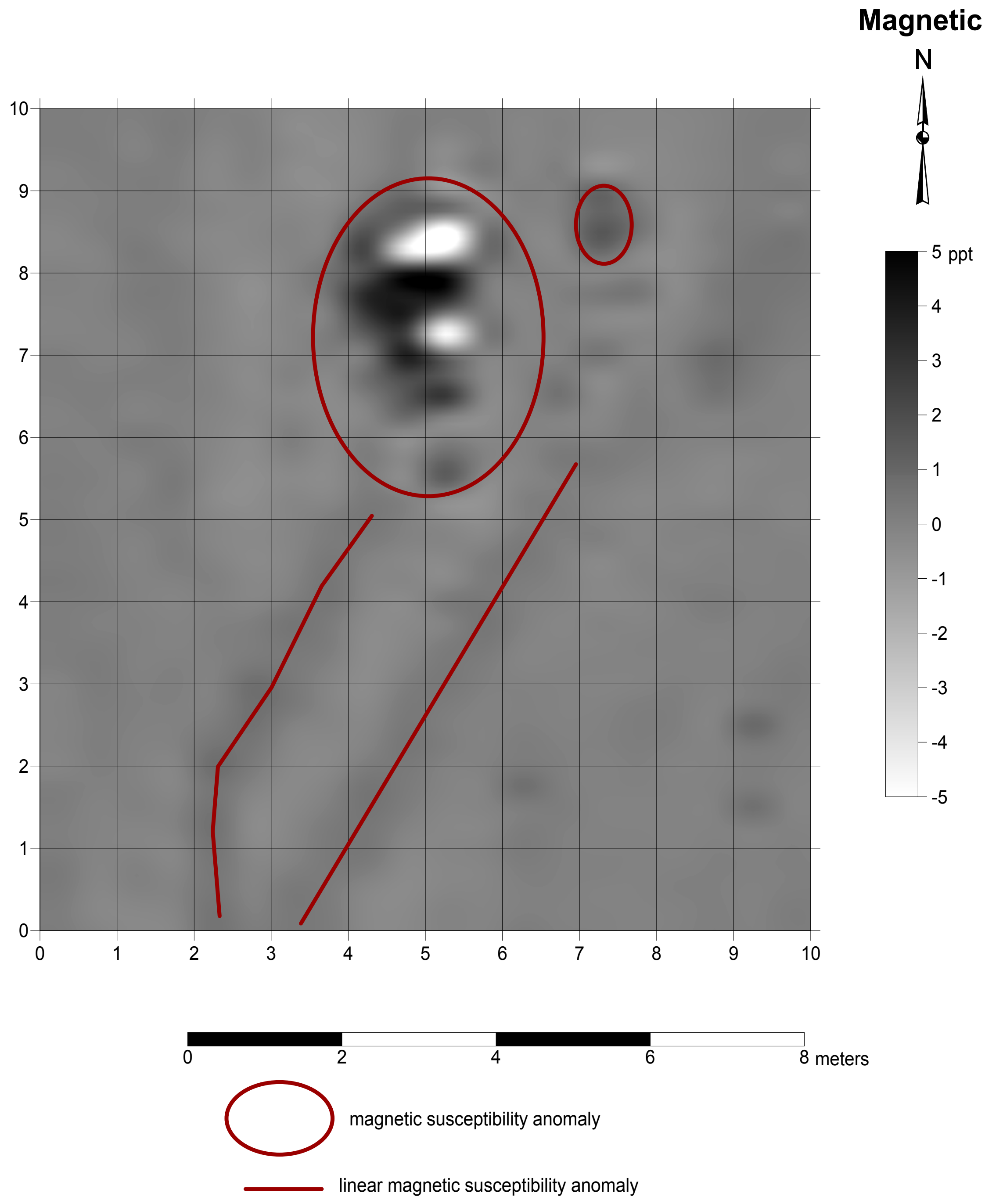


Figure 20. Interpretative map of magnetic susceptibility data from the suspected grave location.

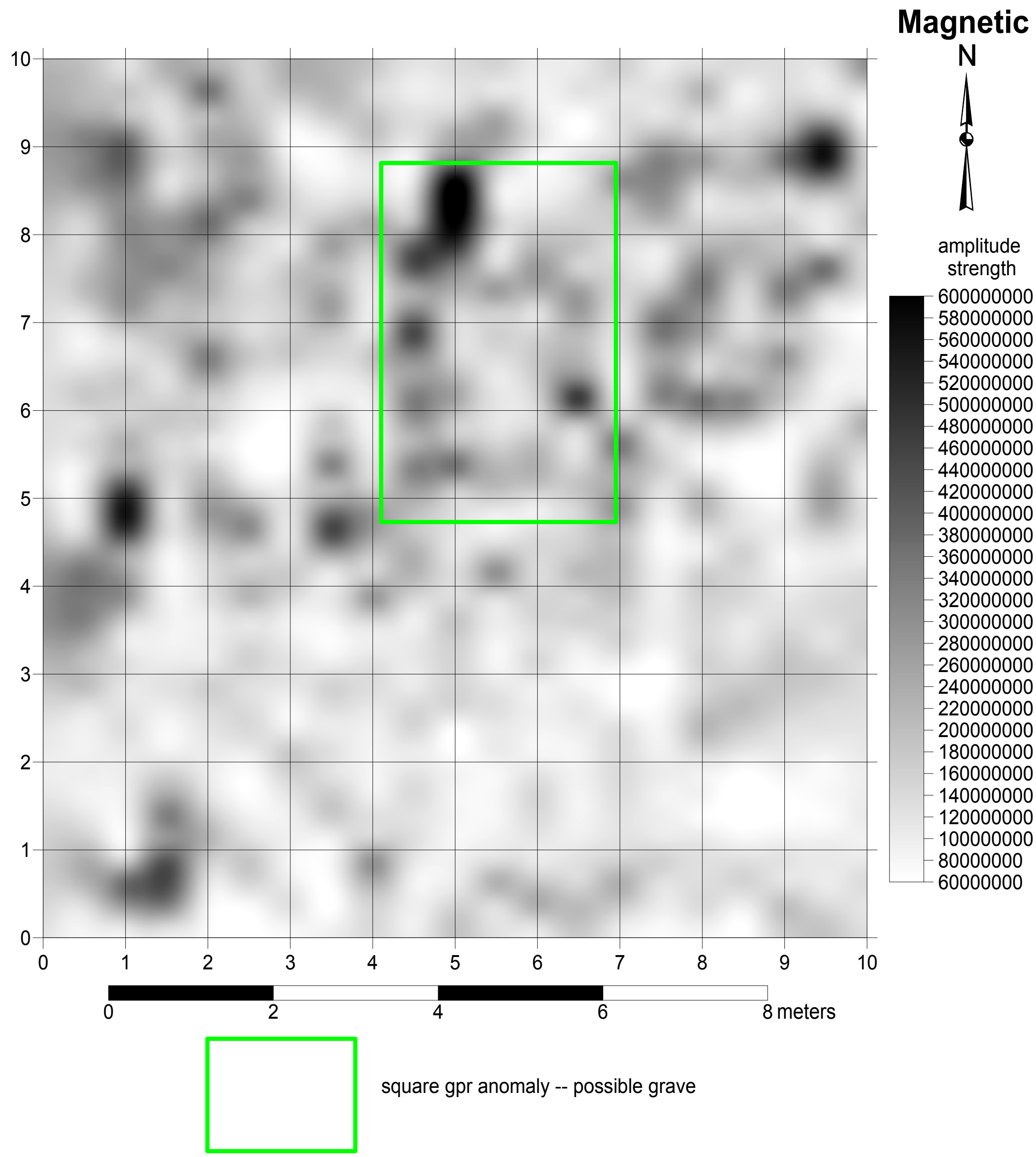


Figure 21. Interpretative map of time slice 5 ground penetrating radar data from the suspected grave location.